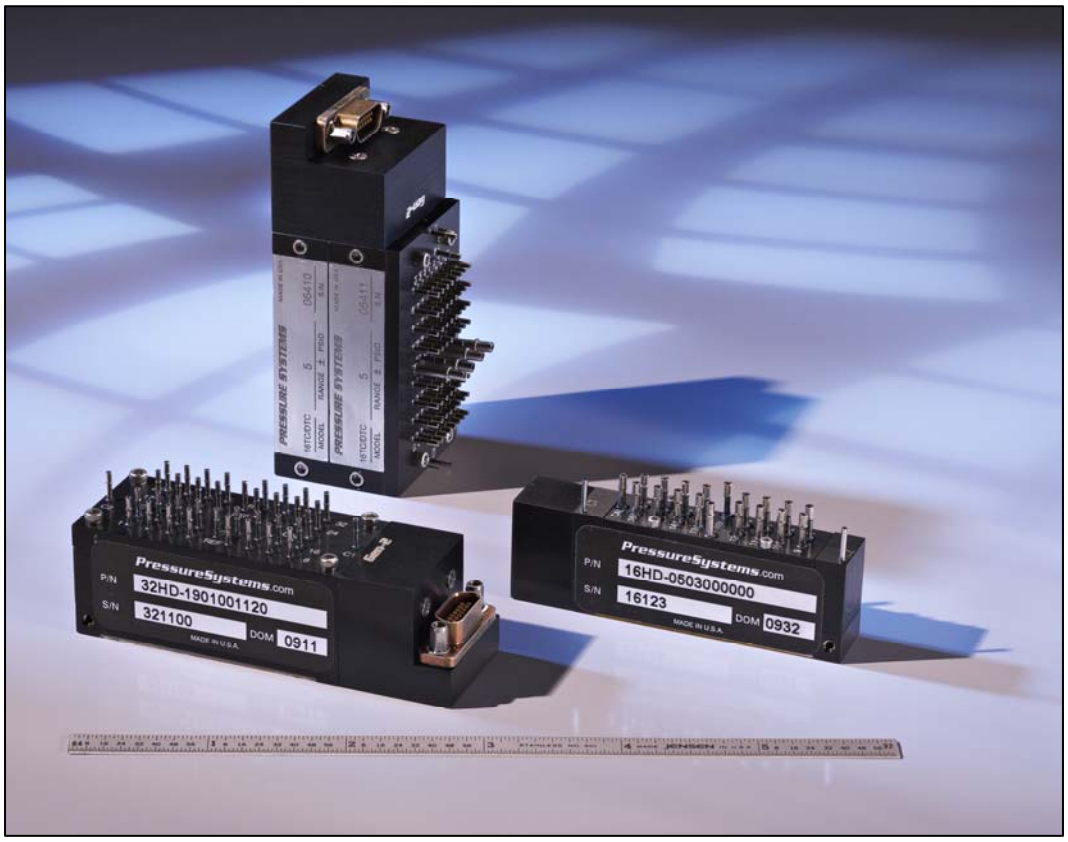
measurement SPECIALTIES
PRESSURE SYSTEMS

ESP Pressure Scanner
User's Manual

August 2009



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Our Company

Pressure Systems develops, manufactures, and services level and pressure measuring instruments where the highest level of traceable accuracy is required for aerospace, industrial, municipal, and environmental applications. Our products have become the world standard for electronic level and pressure measurement and scanning. We are committed to the highest quality design, manufacture, and support of level and pressure instrumentation that is in the best interest of our customers. Pressure Systems is an ISO9001:2000 certified company.

Our Warranty

Pressure Systems warrants this **ESP Pressure Scanner** product to be free of defects in material and workmanship under normal use and service for one (1) year from date of shipment.

Merchandise Return Procedures

If your system seems to be in good working order, but the data seem abnormal, contact the **Applications Support Group** at Pressure Systems. The staff is available for troubleshooting at **(757) 865-1243** or toll free at **1-800-678-7226 (SCAN)** during normal working hours, Eastern time. If the entire system or any part must be returned to Pressure Systems, please obtain a *Returned Merchandise Authorization* (RMA) from the Customer Service Department.

Be prepared to supply the following information when requesting the RMA:

- Part number
- Serial number
- Complete description of problems/symptoms
- **Bill To** and **Ship To** address
- Evaluation/repair purchase order number (not required for warranty repairs)
- Customer contact and telephone number

The above information, including the RMA number must be on the customer's shipping documents that accompany the equipment to be repaired. Pressure Systems also requests that the outside of the shipping container be labeled with the RMA number to assist in tracking the repairs. All equipment should be sent to the following address:

ATTN: CUSTOMER SERVICE (7-digit RMA number)
Pressure Systems, Inc.
34 Research Drive
Hampton, Virginia 23666

Pressure Systems will return North American warranty items prepaid via UPS GROUND. Overseas warranty items will be returned via AIR FREIGHT. If the customer desires another method of return shipment, Pressure Systems will prepay and add the shipping charges to the repair bill.

Incoming freight charges are the customer's responsibility. The customer is also responsible for paying shipping charges to and from the Pressure Systems factory for any equipment not under warranty.

All products covered under warranty policy will be repaired at no charge. An analysis fee will be charged to quote the cost of repairing any item not under warranty. If, for any reason, the customer decides not to have the item repaired, the analysis fee will still be charged. If the quote is approved by the customer, the analysis fee will be waived. The quote for repair will be based on the factory's flat rate for repair, calibration, and board replacement. When these prices do not apply, the quote will be based on an hourly labor rate plus parts. All replaced parts are warranted for 90 days from the date of shipment. The 90-day warranty is strictly limited to parts replaced during the repair.

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Chapter 1

1.0 Introduction

ESP Pressure Scanners are miniature electronic differential pressure measurement units consisting of an array of silicon piezoresistive pressure sensors, one for each pressure port. The sensors are mounted on a common hybrid glass substrate using a proprietary technique which maximizes long term stability. The outputs of the sensors are electronically multiplexed through a single onboard instrumentation amplifier at rates up to 50,000 Hz using binary addressing. The multiplexed amplified analog output is capable of driving long lengths of cable to a remote A/D converter.

The ESP scanners also incorporate a two position calibration manifold actuated by momentary pulses of control pressures. When placed in the calibrate position, all sensors are connected to a common calibration pressure port. A series of accurately measured pressures can be applied through this port to characterize the sensors, in place, at the condition to which they are being subjected. Proper and periodic on-line calibration maintains static errors within +/-0.03% or better of the full scale (FS) pressure range. The calibration manifold automatically switches between two common reference pressures to ensure a stable reference is applied during calibration. The calibration manifold incorporates a visual position indicator and utilizes a dynamic o-ring seal design for high reliability and easy servicing in the field.

Options include purge capability, isolated from the pressure sensors, to clear measurement lines of moisture and contamination as well as to prevent closure of model pressure taps during application of pressure sensitive paint. Other options include a nickel foil RTD output to monitor internal scanner temperature and Digital Temperature Compensation technology now incorporating PSI's Gen-2 amplifier technology.

The Digital Temperature Compensation (DTC) option incorporates the latest PSI innovations in ESP technology including temperature signal outputs from each silicon pressure sensor, embedded EEPROM retaining factory calibration information including temperature characteristics, programmable dual gain amplifier with optional dual range calibration, calibration manifold position sensing, and internal sensor excitation regulation with sense output. DTC Series ESP scanners are supported by PSI's DTC Initium System and the SDI configuration of the System 8400 to dramatically reduce calibration requirements.

This User's Manual will:

- Describe each of the ESP Pressure Scanners produced by Pressure Systems, Inc.
- Provide step-by-step instructions for field repair of the ESP Pressure Scanners

Chapter 2

2.0 Transducer Carrier Description

The transducer carrier used on ESP scanners consists of 16 piezoresistive sensors and two (2) multiplexers bonded to a hybrid substrate encapsulated in a rectangular housing. The silicon pressure sensors have a micro-machined diaphragm onto which four (4) piezoresistors have been diffused. The piezoresistors are connected in a Wheatstone bridge configuration that generates a voltage output proportional to the pressure input. This configuration exhibits low hysteresis and excellent repeatability. Each sensor has a nominal full scale output of 75 mV for pressure greater that 10 psid and 20 to 75 mV for pressures less than 10 psid. The carrier design (see **Figure 2.1**) incorporates O-ring pressure seals for measurement, calibration, and reference inputs, and is mounted to the scanner with two (2) Allen-head screws. This design allows for easy O-ring replacement without the need for special skills or tools. (See **Chapter 6 Repair and Maintenance**)

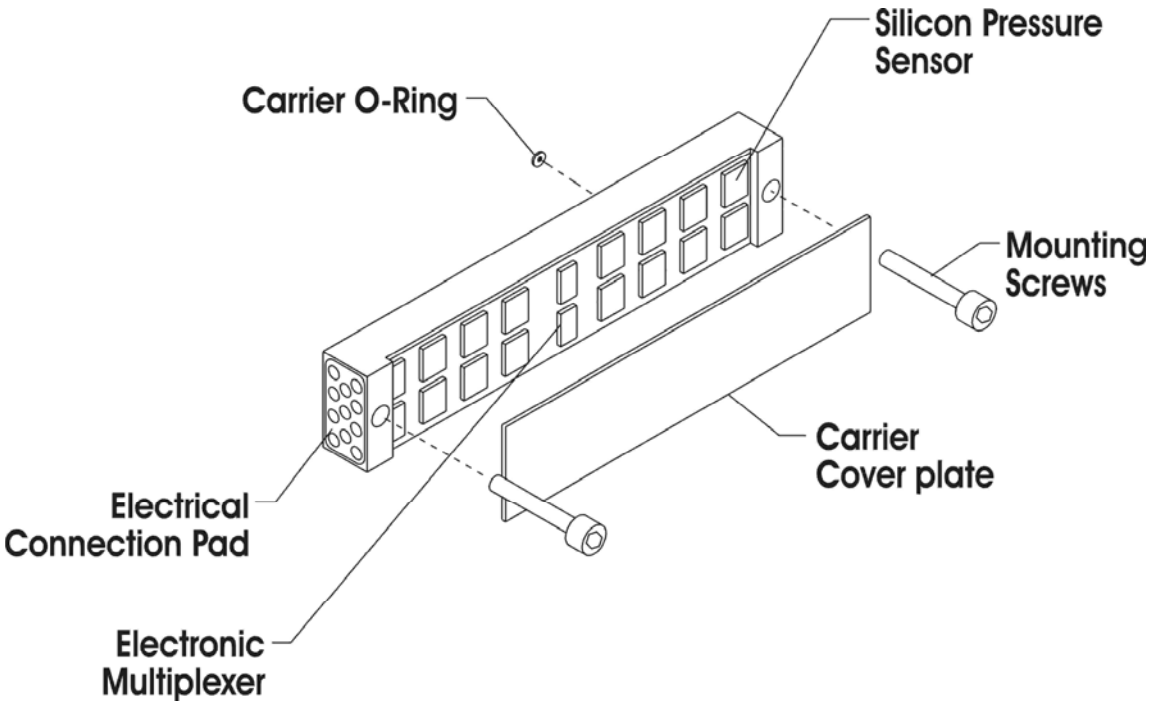


Figure 2.1: Transducer Carrier Exploded View

2.1 Scanner Description

ESP pressure scanners offer many advantages due to the unique features inherent in their design. Attributes such as individual sensor thermal compensation and automatically switched reference pressures greatly enhance performance benefitting the windtunnel and flight test industry while the modular design facilitates serviceability in the field.

Figures 2.2 through **2.4** are exploded views of the ESP-16HD, ESP-32HD, and ESP-64HD scanners. Please refer to these drawings to understand the construction of the pressure scanners.

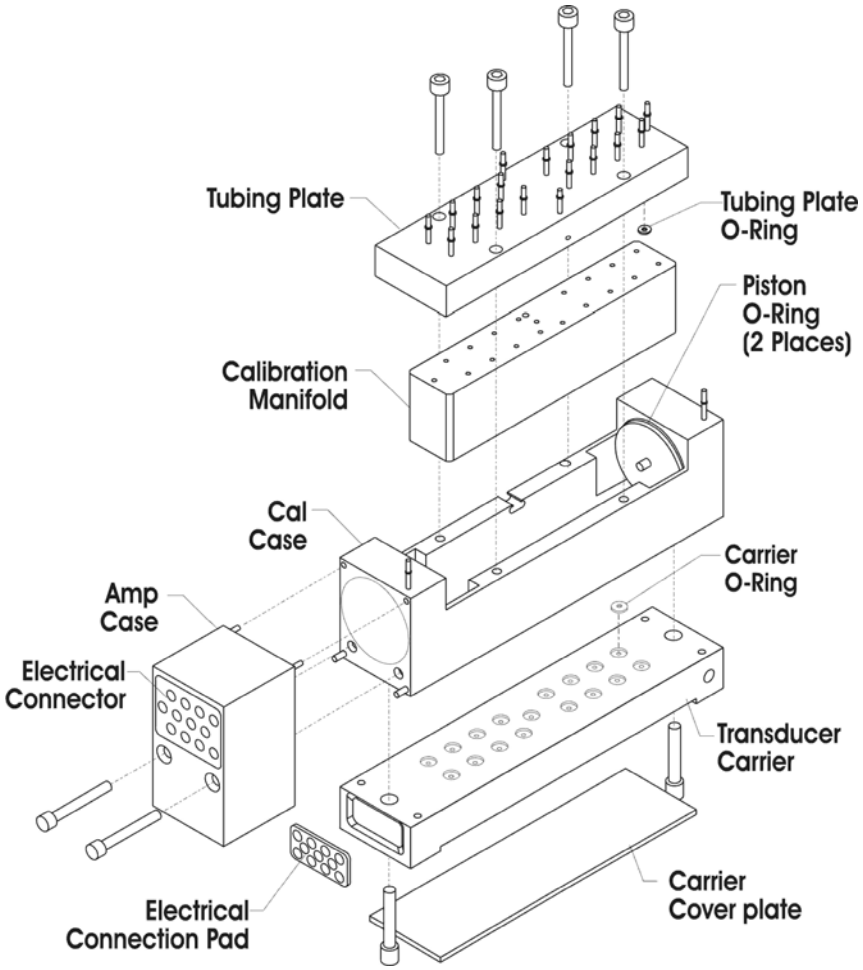


Figure 2.2: ESP-16HD Exploded View

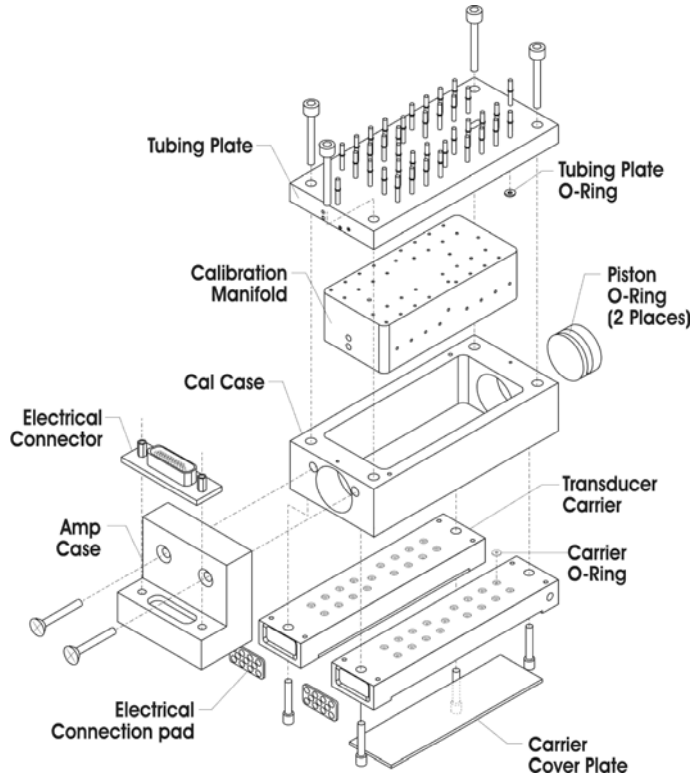


Figure 2.3: ESP-32HD Exploded View

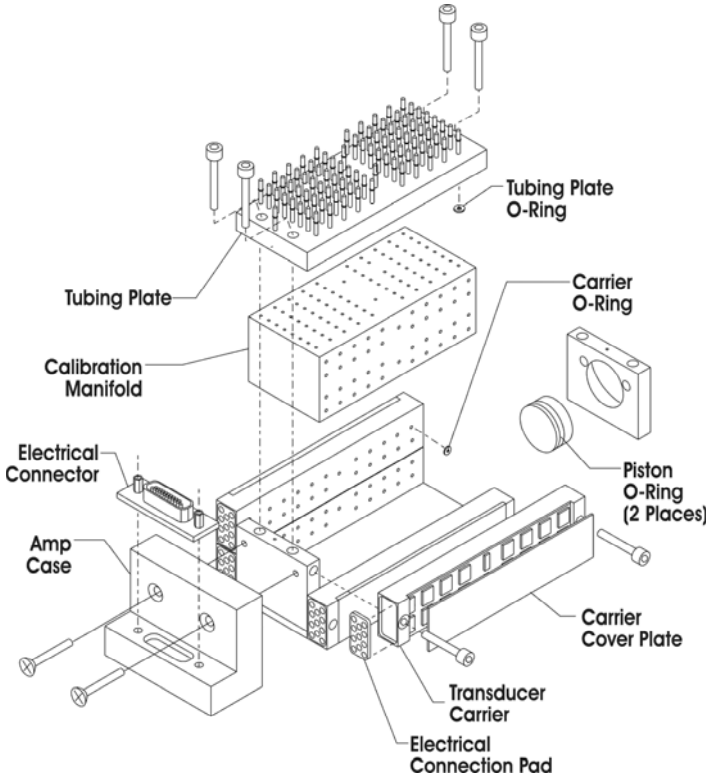


Figure 2.4: ESP-64HD Exploded View

2.2 Pneumatic Description

All ESP scanners require a minimum of three pneumatic inputs for operation; two control pressures (C1 and C2), and a calibration pressure. Applying 100 psig (700 kPa) (dry air or nitrogen) to the C1 control port switches the internal calibration manifold to the Calibrate position. With the manifold in this position, all sensors are manifolded to two common ports, one CAL and one CAL REF. The CAL port is manifolded to the input or run side of the sensors and the CAL REF port is manifolded to the reference side of the sensors. By applying calibration pressure(s) to the CAL port, all sensors can be calibrated in the environment to which they are subjected. CAL REF is used to input atmospheric reference or another stable pressure during calibration.

After calibration, the manifold may be switched to the Run position by applying 100 psig (700 kPa) to the C2 control port (pressure on C1 must be vented). In this position, each sensor is pneumatically connected to its associated input port. A manifold position indicator pin, located in the center of the tubing plate, clearly shows the position of the internal calibration manifold. The RUN REF port is the reference pressure input when in the Run position and is manifolded internally to the reference of each of the sensors within the scanner. The RUN REF port is typically connected to tunnel static pressure, atmosphere, vacuum, etc., but care should be taken that only dry gas (or vacuum) is attached to this port. An input port diagram is shown in **Figure 2.7**. Refer to this diagram when connecting tubing to the scanner. To understand the operation of the internal manifold, refer to the calibration manifold diagram shown in **Figure 2.6**.

Note

Over-pressuring the scanner (on the inputs, CAL, or REF ports) can cause damage to the scanner. Check, then recheck all pneumatic connections before applying pressure.

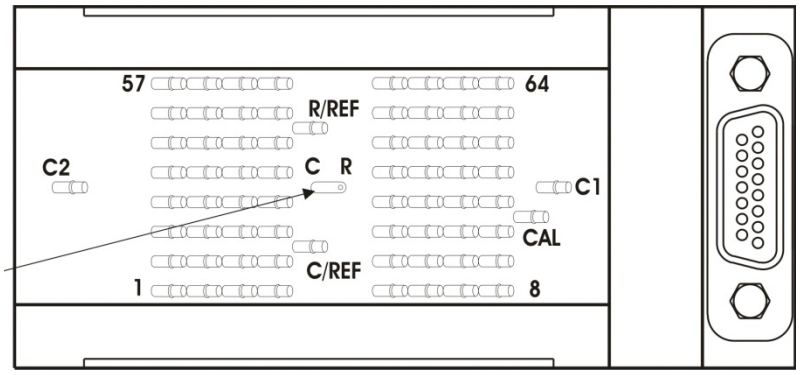


Figure 2.5: Input Port Diagram

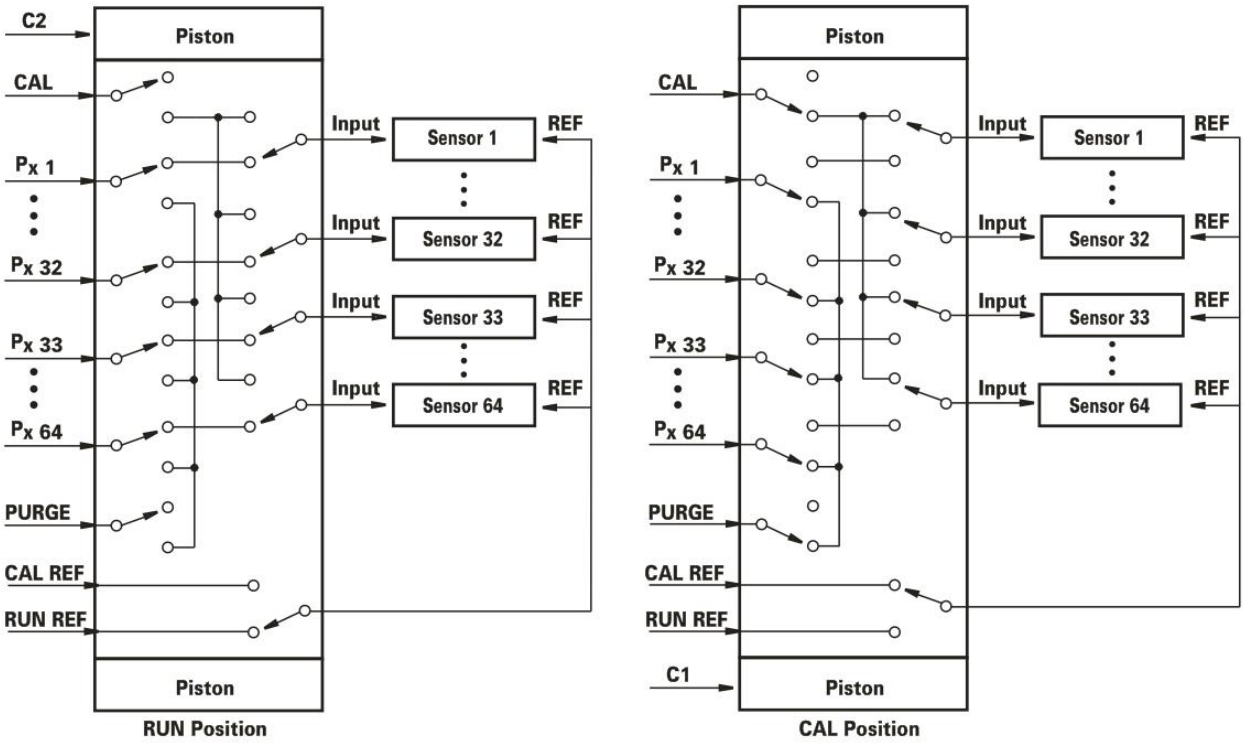


Figure 2.6: Calibration Manifold Diagram

Chapter 3

3.0 Conventional ESP Scanner Description

Conventional ESP Pressure Scanners represent PSI's second generation of miniature ESP scanners. These "HD-style" ESP scanners are all built upon the 16 channel transducer carrier described in **Section 2.0 Transducer Carrier Description.** Conventional HD-style ESP scanners offer many advantages over their predecessors such as individual sensor thermal compensation, modular construction, and automatically switched reference pressures that greatly enhance performance while easing user considerations and facilitating service in the field.

Individual sensor thermal compensation is accomplished by adding a precision resistor network to the sensor's Wheatstone bridge to reduce sensor offset and thermal zero shifts. Thermal span shifts are reduced using a thermistor to alter the amplifier's gain proportional with temperature. Using these techniques, both zero and span shifts with temperature inherent in silicon pressure sensors are dramatically reduced.

Conventional ESP scanners require a multipoint on-line calibration prior to use as described in **Section 3.2 Conventional ESP Scanner Calibration** to correct for sensor offset, span, and non-linearity when calculating pressure measurements in engineering units. Regular on-line rezero and/or span calibrations throughout a test maximizes scanner accuracy in changing temperature environments and over lengthy test durations.

An optional temperature sense output as described in **Section 5.2 Temperature Sense Option** can be added to indicate internal scanner temperature. When used with calibration data taken of the scanner at various temperature intervals, digital temperature correction can be employed using microcomputer intelligence. The temperature sense option is also supported by a number of third party systems.

Refer to Appendix A for Conventional ESP specification drawings.

3.1 Electrical Description

Electrical interfacing to conventional ESP Pressure Scanners is relatively simple and straightforward. All electrical inputs and outputs are brought out on connector J1. Refer to **Table 3.1** and **Figure 3.2** for connector J1 pinouts for ESP-16HD and connector pin locations. Refer to **Table 3.2** and **Figure 3.3 for** connector J1 pinouts for ESP-32HD and ESP-64HD.

A ±12 VDC and a +5 VDC supply are required to power the scanner. The +5 VDC supply is the voltage between V_s and $-V_s$ for sensor bridge excitation and must be regulated at or near the scanners to within ±0.02%. The digital addresses A_0-A_5 determine which sensor output will be present on the voltage output line V_0. They should be open-collector buffered to drive long interface cables. The digital address lines are 12 VDC logic. Logic 0 is ≤ 3 VDC, logic 1 is ≥ 8 VDC. At a maximum distance of 30 feet from the scanner, the open-collector address lines must be tied to the CMOS levels before being input into the scanner. The A/D converter should be at least 12 bits resolution. Connector J1 should be connected with the proper signals on the appropriate pins before applying power to the scanner. After addressing the desired sensor, no less than 50 microseconds should be allowed for the multiplexers and amplifier to settle before acquiring data. The ESP-16HD uses A_0-A_3, the ESP-32HD uses A_0-A_4, and the ESP-64 uses A_0-A_5.

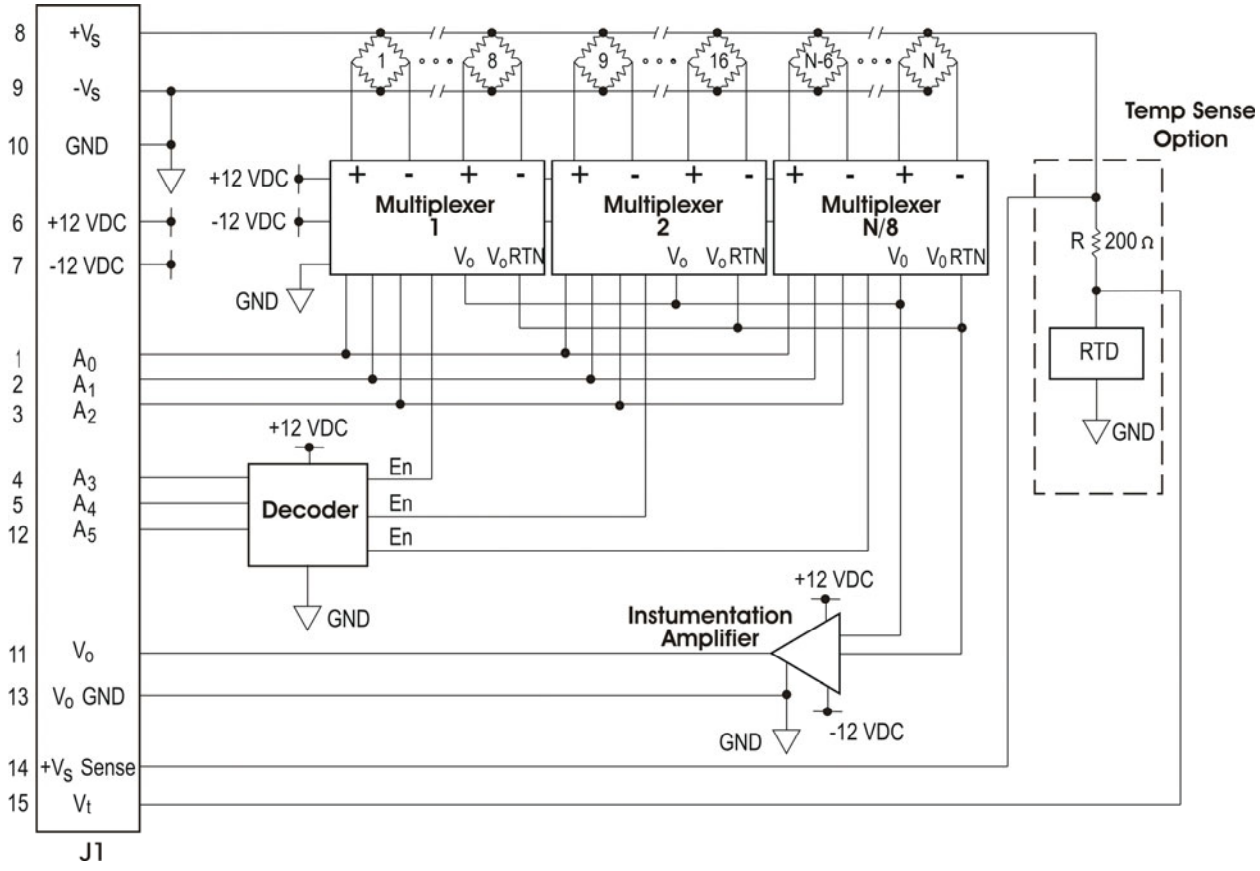
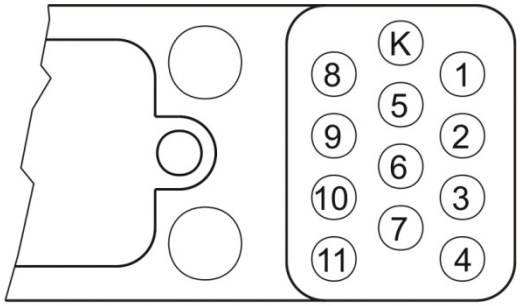


Figure 3.1: Electrical Diagram for Conventional ESP Scanners

PIN	FUNCTION	PIN	FUNCTION
1	**A_0**, Digital Address	7	**-12 VDC** Supply Voltage
2	**A_1**, Digital Address	8	**$+V_s$**, Sensor Supply Voltage (+5 VDC)
3	**A_2**, Digital Address	9	**$-V_s$**, Sensor Supply Voltage (RTN)
4	**A_3**, Digital Address	10	**GND**
5	**V_t**, Temperature Sense Output	11	**V_o**, Pressure Voltage Output
6	**+12 VDC** Supply Voltage	K	Alignment Key

Table 3.1: ESP-16HD Connector J1 Pinout



PIN NUMBERS LOOKING INTO CASE

Figure 3.2: ESP-16HD Connector Pin Locations

PIN	FUNCTION	PIN	FUNCTION	PIN	FUNCTION
1	**A_0**, Digital Address	6	**+12 VDC** Supply Voltage	11	**V_o**, Pressure Voltage Output
2	**A_1**, Digital Address	7	**-12 VDC** Supply Voltage	12	**A_5**, Digital Address
3	**A_2**, Digital Address	8	**$+V_s$** Sensor Supply Voltage (+5 VDC)	13	**V_0 GND**
4	**A_3**, Digital Address	9	**$-V_s$**, Sensor Supply Voltage (RTN)	14	**$+V_s$ Sense**
5	**A_4**, Digital Address	10	**GND**	15	**V_t**, Temperature Sense Output

Table 3.2: Conventional ESP-32HD and ESP-64HD Connector J1 Pinout

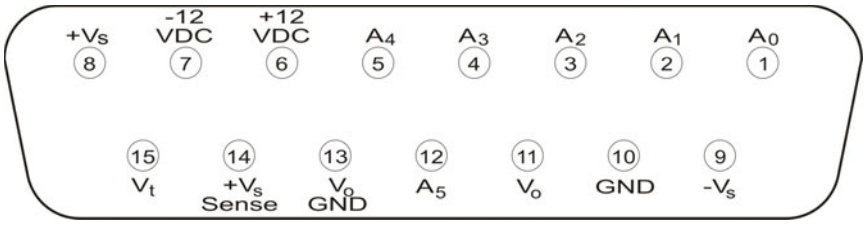


Figure 3.3: Conventional ESP-32HD and ESP-64HD Connector Pin Locations

3.2 Conventional ESP Scanner Calibration

The accuracy of the ESP scanner is maintained through periodic on-line calibrations. A calibration consists of pneumatically switching the scanner calibration manifold into the calibrate position, and then applying multiple calibration pressures while monitoring the electrical response of each sensor within the scanner. The calibration data for each of the sensors may be reduced into offset, sensitivity, and non-linearity coefficients that are used to calculate unknown pressures. The following fourth-order polynomial resulting from a five-point calibration is used to calculate pressure during data acquisition.

$$P_x = C_0 + C_1 (v_x) + C_2 (v_x)^2 + C_3 (v_x)^3 + C_4 (v_x)^4$$

Where:

P_x	=	pressure to be measured
C_0	=	offset (psi)
C_1	=	sensitivity (psi/volt)
C_2	=	non-linearity (psi/volt^2)
C_3	=	non-linearity (psi/volt^3)
C_4	=	non-linearity (psi/volt^4)
v_x	=	sensor voltage at P_x

At a minimum, a three-point pressure calibration is required to generate a non-linearity (C_2) term for each sensor. The frequency of calibration is dependent on ambient temperature changes and electrical drift of the sensors with time. An automatic calibration system is highly desirable for these scanners, allowing calibrations to be made as frequently as practical. A five-point calibration performed immediately before a set of data is acquired assures the highest accuracy (±0.05% FS) of conventional scanners.

The calibration manifold may also be used to execute a simple on-line re-zero of the sensors. This process requires the manifold to be switched to the Calibrate position while exposing the CAL port and the CAL REF port to the same pressure (typically atmosphere), and acquiring the sensor analog outputs at this condition. This allows a new zero term to be established and eliminates both zero drift and thermal zero shift errors.

Chapter 4

4.0 DTC Series Scanner Description

The Digital Temperature Compensation (DTC) Series of ESP Pressure Scanners incorporates many advanced features to increase the utility of the scanners while providing temperature compensation of the silicon sensors. DTC Series scanner capabilities are used by the DTC Initium and the System 8400 SDI (scanner digitizer interface).

An onboard EEPROM stores the thermal calibration data for each channel. Also stored in the EEPROM is information identifying the range of the scanner, the number of channels, the model number, the serial number, the date of manufacturer, the date of calibration, and the model and serial number of the calibration unit used to calibrate the scanner. This data is serially transmitted to a data acquisition system such as the DTC Initium or to the Scanner Digitizer Interface (SDI) of the System 8400 using the ESP address lines and then transferred to the 8400 System Processor via fiber optic cable.

Using a proprietary PSI-developed method, the temperature of each sensor within the scanner is measured and transmitted along with the raw pressure measurements to the data acquisition system. Utilizing the calibration data within the EEPROM, the data acquisition system compensates for temperature changes to the sensors in real time. This reduces thermal errors by a factor of 20 thereby reducing on-line calibration requirements by up to 90%. In addition, only zero and span calibration is required to provide accuracy better than ±0.03% FS immediately after calibration.

The ESP scanners also incorporate a Hall Effect sensor which is used to indicate the position of the calibration manifold. This position information can be transferred to the system upon command.

Another advanced feature is the ability to derange the ESP scanner upon command. This alters the gain on the amplifier to derange the scanner by a factor of three, enabling additional windtunnel tests to be conducted without re-instrumenting the model with lower range ESP scanners. In order to maximize the performance of the scanners in the deranged mode, the DTC Series ESP scanners should be factory-calibrated for dual range operation.

DTC Series ESP scanners are slightly longer than conventional scanners to accommodate the additional electronics in the amplifier assembly. The DTC scanners now use PSI's Gen-2 amplifier design providing the ultimate in performance requiring only a 20 microsecond settling time between channel addresses providing scan rates of 50,000 channels per second.

Refer to Appendix A for DTC Series ESP specification drawings.

4.1 Electrical Description

Although DTC Series ESP scanners contain additional functionality, compatibility with conventional ESP scanners has been maintained. A block diagram of the DTC scanner is depicted in **Figure 4.1**. The sensor's excitation is internally derived from the +12 VDC power to improve regulation and to eliminate the need for another externally regulated supply. The scanner's calibration coefficients are stored in a 64K bit serial EEPROM. The dual gain amplifier, in conjunction with the optional dual range calibration, allows a windtunnel model to be tested in various configurations without changing to scanners of another pressure range. A second multiplexed analog line outputs temperature sense, excitation sense, and calibration manifold position signals as well as being used to output memory data. The six (6) digital address lines select one of the scanner's pressure sensors to be present on the voltage output line V_0. Address lines A_4 and A_5 also support a two-wire serial bus to access the EEPROM, select gain, or select the second multiplexed analog output.

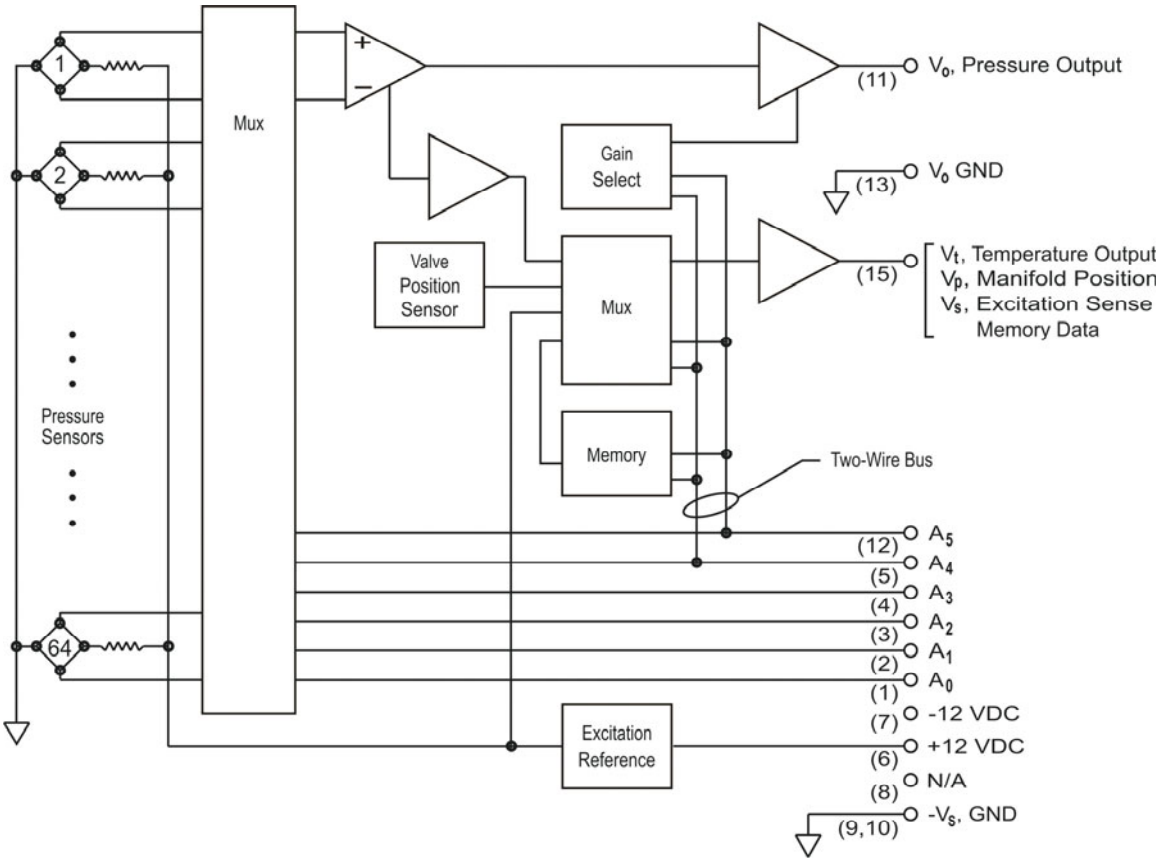


Figure 4.1: Electrical Diagram for DTC Series ESP Scanners

PIN	FUNCTION	PIN	FUNCTION	PIN	FUNCTION
1	**A_0,** Digital Address	6	**+12 VDC** Supply Voltage	11	**V_o**, Voltage Output
2	**A_1**, Digital Address	7	**-12 VDC** Supply Voltage	12	**A_5**, Digital Address
3	**A_2**, Digital Address	8	**N/A** (Not Used)	13	**V_0 GND**
4	**A_3**, Digital Address	9	**$-V_s$**, Sensor Supply Voltage (RTN)	14	**N/A** (Not Used)
5	**A_4**, Digital Address	10	**GND**	15	**Muxed Out**put (V_t, V_s, V_p)

Table 2.2: DTC Series ESP-32HD and ESP-64HD Connector J1 Pinout

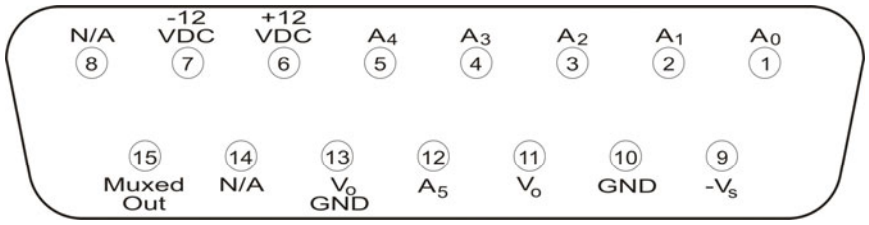


Figure 2.4: DTC Series ESP-32HD and ESP-64HD Connector Pin Locations

4.1 DTC Series ESP Scanners Calibration

While piezoresistive silicon pressure sensors offer high reliability with ultra-miniature size, the sensors are sensitive to temperature and must be compensated for thermal effects. The uncompensated thermal offset shift may exceed ±0.1%FS/ºC and when using constant voltage excitation, the uncompensated thermal span shift is about -0.24%FS/ºC.

With DTC Series scanners, repeatable thermal effects are characterized to allow digital correction of offset, span, and linearity over the scanner's operating temperature range. Initially, a single sensor was used to measure the scanner's temperature. However, thermal gradients between it and each pressure sensor limited the achievable performance. By using pseudo-constant current excitation, individual temperature signals can be derived from each pressure sensor. The excitation and A/D zero reference are also measured to operate in a zero corrected ratiometric mode:

$$p_r = (c_p - c_z) \div (c_e - c_z)$$

$$t_r = (c_t - c_z) \div (c_e - c_z)$$

Where:

p_r	=	*raw pressure ratio*
t_r	=	*raw temperature ratio*
c_p	=	*raw pressure measurement*
c_t	=	*raw temperature measurement*
c_e	=	*raw excitation measurement*
c_z	=	*raw zero reference measurement*

The temperature signal, derived from each sensor's bridge resistance, is also affected by pressure. To compute calibration coefficients which can be used at constant temperature, this unwanted pressure effect must be removed:

$$t_c = Q_0 + Q_1 t_r + (R_0 + R_1 t_r) p_r + (S_0 + S_1 t_r) p_r^2$$

Where:

t_c	=	*pressure corrected* t_r
$Q_0, Q_1, R_0, R_1, S_0, S_1$	=	*calibration coefficients*

Once this has been done, the following pressure conversion coefficients are calculated from the current temperature:

$$A = A_0 + A_1 t_C + A_2 t_C^2 + A_3 t_C^3$$
$$B = B_0 + B_1 t_C + B_3 t_C^3$$
$$C = C_0 + C_1 t_C$$
$$D = D_0 + D_1 t_C$$

Where:

A, B, C, D	=	*coefficients for current temperature*
A_0, A_1, A_2, A_3	=	*calibration coefficients*
B_0, B_1, B_2, B_3	=	*calibration coefficients*
$C_0, C,$	=	*calibration coefficients*
D_0, D_1	=	*calibration coefficients*

To reduce the computational overhead, these calibrated coefficients (a-d) can be used to compute pressures until a new temperature update is required:

$$P_c = A + B p_r + C p_r^2 + D p_r^3$$

Since this compensation algorithm can only correct for repeatable effects over temperature and pressure, the pressure sensors are selected for low offset drift, low span drift, and good thermal closure (hysteresis). Additional temperature and pressure cycles are used to further select sensors with low pressure hysteresis, low temperature hysteresis, and high accuracy over temperature and pressure points within the operating range.

Correction coefficients to remove the unwanted pressure effect on the temperature signal are computed using a least squares surface fit of the raw temperature and pressure ratio to the corrected temperature ratio. In a similar way, thermal calibration coefficients are computed using another least squares surface fit of raw pressure and corrected temperature ratio to the applied pressure. Once these coefficients are determined during manufacturing, they are stored within the scanner's non-volatile memory.

Two additional coefficients can be determined with a single 2-point pneumatic calibration. These coefficients provide real time offset and span adjustment:

$$P = S (P_c + Z)$$

Where:

S	=	*span adjustment*
Z	=	*zero adjustment*

Note

DTC Series scanners may also be used as conventional scanners; however, they must be calibrated in the same manner as conventional scanners. See Section 3.2 Conventional ESP Scanner Calibration

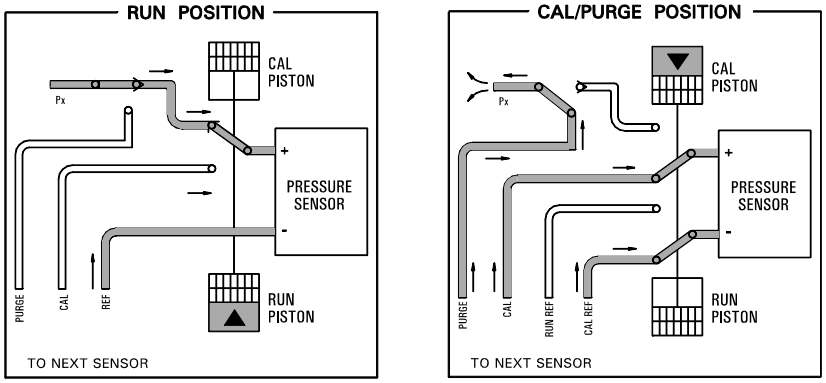
Chapter 5

5.0 Purge Option

The purge option involves a modification to the scanner's calibration manifold to connect purge pressure inputs to the measurement ports during calibration. Anytime the manifold is placed in the calibrate position, purge pressure applied to the purge ports will purge the measurement lines of any contamination such as moisture. This option enables simultaneous purging and calibration (or rezero) which is especially useful in flight test applications. The purge option is also useful for preventing model surface pressure taps from becoming clogged during the application of pressure sensitive paint.

Note

Purge pressure must be present whenever the manifold is shifted to the calibrate position to prevent "reverse" purge from occurring.



The purge option allows the ESP input pressure lines to be purged of contaminants. Purge pressure is input to the scanner via bulged purge tubulations. The ESP-64HD utilizes four 0.090" OD (0.063" OD for the angled QDC option) purge tubulations whereas the ESP-32HD and the ESP-16HD both only utilize one of 0.125" OD and 0.063" OD, respectively. The purge pressure is isolated from the sensors thereby eliminating possible damage due to overpressure. This option can be ordered as a factory installed option or a user-installed kit.

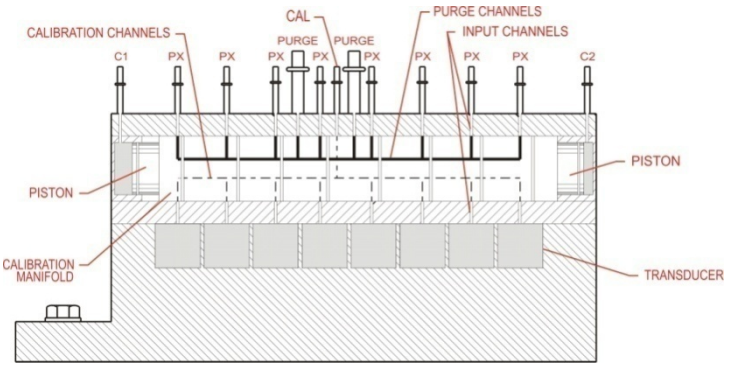


Figure 5.1: Purge Mode Diagram

5.1 Heater Chambers

ESP Heater Chambers are designed to maintain the scanner at operating temperatures within -25 to 80ºC. The heater chamber is constructed of Delrin material, an acetate resin that is both lightweight and a good insulator. Heater chambers are available for the ESP-16HD, 32HD, and 64HD pressure scanners.

Refer to Appendix B for all heater chamber specification drawings.

The heater chamber electronics include protection from thermal overload should internal heater chamber temperatures approach 90ºC as well as potentiometer adjustment of heater chamber temperature (preset at the factory to user specifications). The entire electronics package, including the scanner, is encased in a copper liner to maintain even temperature distribution. The heater chamber requires +28 VDC power to the two leads which are left unterminated for user installation. A scanner cable is required to pass through the top plate of the heater chamber to connect to the scanner.

Table 5.1 gives the setpoint in ohms for a given desired temperature setting. The following procedure can be used to adjust the heater temperature.

1. Determine a setpoint temperature fitting the application.
2. Connect an Ohmmeter to the two test points on the Heater Chamber.
3. Adjust the potentiometer until the control setpoint value in ohms from the chart is indicated on the meter.

Note 1: This procedure results in a temperature setting within ±3º of the desired setpoint.

Note 2: The heating element in the heater chamber can develop about 33 watts of power. The chamber provides insulation; however there are limitations for achievable regulation. The Heater Chamber reduces the temperature effect to the scanner by a factor of 10:1.

Note 3: It is recommended to set the Heater Chamber temperature setpoint to 5ºC above the expected ambient temperature. Maximum scanner temperature environment is 80ºC.

Note 4: For operation in a very cold environment (-50ºC), it is important to set the temperature to above freezing (0ºC), so water condensation does not occur.

Note 5: Factory default temperature setpoint is 40ºC.

ºC	Control Setpoints in Ohms	ºC	Control Setpoints in Ohms	ºC	Control Setpoints in Ohms	ºC	Control Setpoint in Ohms
0	43.8225	21	48.85167	42	55.55962	63	59.42491
3	44.53217	24	49.58264	45	56.32418	66	60.21115
6	45.24462	27	50.317	48	52.54127	69	61.00197
9	45.95994	30	51.05483	51	53.29005	72	61.79748
12	46.67822	33	51.79623	54	57.09291	75	62.59774
15	47.39955	36	54.09291	57	57.86588	78	63.40287
18	48.124	39	54.79913	60	58.64319	81	64.21291

Table 5.1: Resistance Temperature Chart

5.2 Temperature Sense Option

The Temperature Sense option is only available on conventional ESP scanners and provides an analog output from a nickel-foil RTD (Resistive Temperature Detector) located on the ESP amplifier PCB (printed circuit board) to indicate internal scanner temperature. The signal is output via pin 15 of the electrical connector. This option can be used with common data acquisition systems to perform digital thermal compensation of the sensors.

Silicon sensors are repeatable with temperature and, once characterized, can be compensated for thermal errors using algorithmic techniques. A fourth order polynomial equation is generated for each sensor at standard temperature points of -25, 0, 25, 50 and 75ºC. These equations as well as the corresponding RTD voltages are provided to customers in a calibration report along with the scanner.

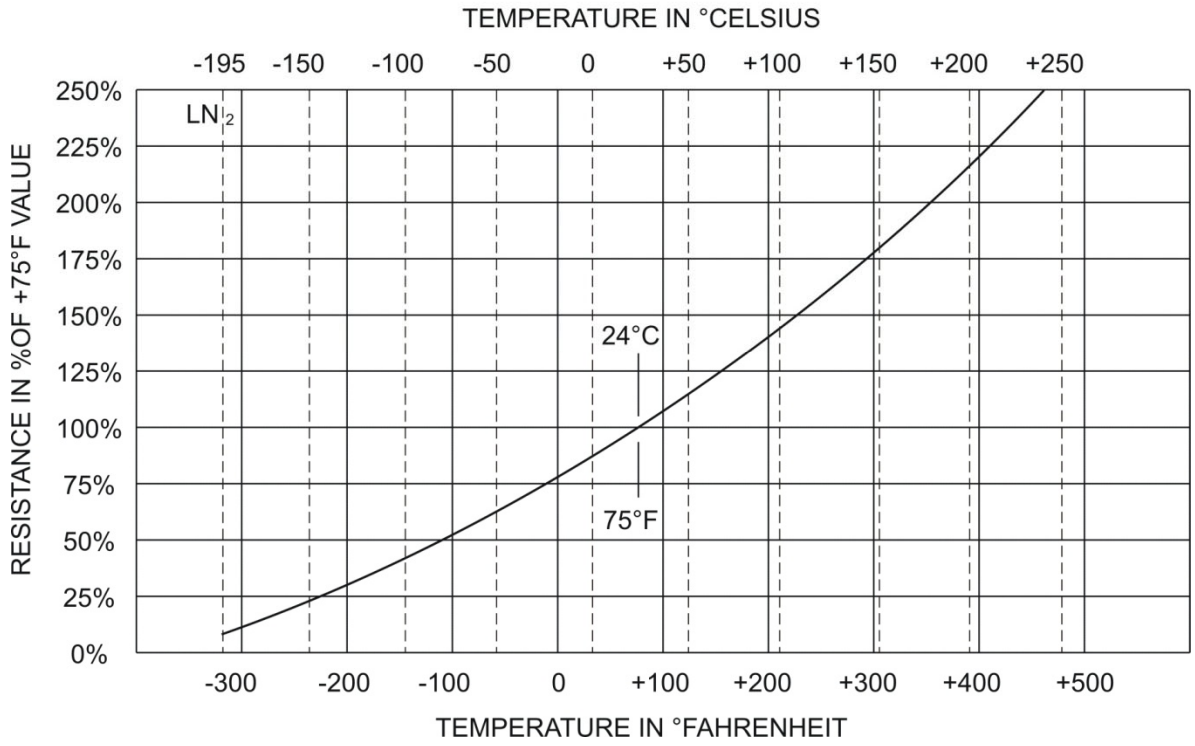


Figure 5.2: Resistance vs. Temperature Curve

5.3 Pneumatic Connections

Pneumatic connections to the ESP scanners are made via user-specified 0.040" or 0.063" OD bulged stainless steel tubulations installed on the scanner tubing plate. Tubulations of 0.040" OD can optionally be installed at a 60º angle to minimize the overall height of the scanner. Scanners specified with Purge option must be installed at the standard 90º angle unless the Quick-Disconnect option is also specified.

Flexible tubing is installed over the bulged tubulation and secured using retaining springs. Pressure Systems offers nylon tubing, retaining springs and tubing pliers to facilitate the installation of the tubing and springs.

5.4 Quick-Disconnect Option

The Quick-Disconnect option enables users to easily disconnect the tubing plate from the ESP scanner without compromising manifold integrity by exposing the internal calibration manifold to potential contaminants. Separating the tubing plate from the scanner helps reduce setup times by allowing tubing connections to be completed while simultaneously conducting electrical checkout of the scanner. The Quick-Disconnect option also now enables angled tubulation to be specified in conjunction with the Purge option.

Quick-Disconnect tubing plates can be ordered as an option on new ESP scanners or as a retrofit kit for field installation. Each kit comes with installation instructions and is comprised of four (4) components: tubing plate, receiver plate, and two protective cover plates. Individual components may also be ordered as replacements.

Refer to Appendix A for Quick-Disconnect ESP specification drawings

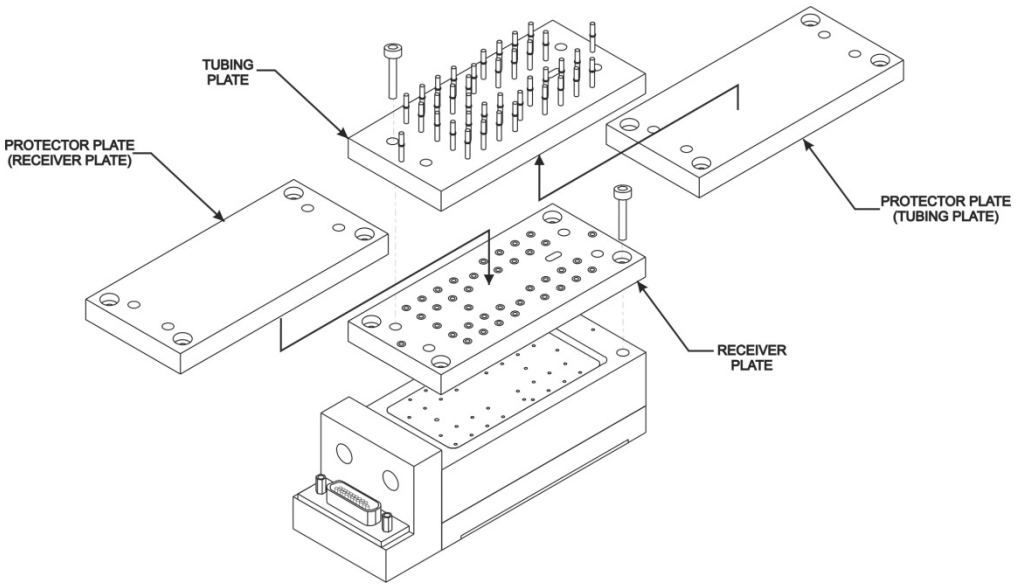


Figure 5.3: Quick-Disconnect ESP Exploded View

Chapter 6

6.0 Repair and Maintenance

ESP scanners are field repairable to the extent of O-ring and tubulation replacement. To facilitate repair of the scanners, maintenance kits are available for each ESP scanner. Kits include spare bulged tubulations, a drill bit to clean the tubulation bore in the tubing plate, and the sealant to secure the tubulation to the plate. Also included are spare O-rings for the transducer carrier, tubing plate, and pistons, along with a supply of lubricant. Additional O-rings may be separately purchased. See **Appendix C Spare Parts**.

Note

All ESP scanners and transducer carriers are sensitive to electrostatic discharge

6.1 O-Ring Replacement Procedures

The following tools are necessary for O-ring replacement:

- One #0 Phillips-head screwdriver (PSI PN: 38-01-07-0)
- One 5/64" Allen-head screwdriver (PSI PN: 38-01-08-0564)
- One needle-nose tweezers

The components needed for O-ring replacement are included in ESP maintenance kit (PSI PN: ESP-MK) or may be ordered separately. Needed for these procedures are O-rings (two sizes), a fast evaporating cleaning fluid (i.e., acetone, alcohol, Freon, etc.), 50 psi dry air supply, and Krytox® fluorinated grease (PSI PN: 41-06-KRYX). *Thoroughly read product recommendations and warnings*. PSI recommends using cotton-tipped, lint-free applicators to apply cleaning fluid.

6.1.1 Tubing Plate O-Ring Replacement

1. Using the Allen-head screwdriver (PSI PN: 38-01-08-0564), loosen the two screws (one-half turn) on all carriers. Do not loosen these screws more than one-half turn. Use an Allen wrench (PSI PN: 38-01-08-050 for ESP-16HD or PSI PN: 38-01-08-0564 for ESP-32HD and ESP-64HD to remove the four Allen-head screws that secure the tubing plate onto the scanner. Carefully slide the tubing plate back and forth (about ¼ of an inch) several times. This is done to loosen the O-rings from the calibration manifold. Lift the tubing plate straight up.

2. Remove the O-rings from the tubing plate that are in need of replacement, using the needle nose tweezers. Clean the O-ring cup with an applicator moistened with a cleaning fluid such as acetone, alcohol, or Freon (read all manufacturer's warnings thoroughly), or any other substance that evaporates quickly and leaves very little residue. Remove any excess cleaner with the air supply as soon as possible.

3. With clean hands, apply a small amount of Krytox® grease (PSI PN: 41-06-KRYX) to the palm of one hand and spread it evenly with your index finger. Place one new O-ring

onto your greased palm. Work the O-ring around until it is evenly greased. The O-ring should shine when properly greased and there should be no white areas of excess grease on the O-ring. Make sure there is only a thin film of grease on the O-ring. Using your greased index finger, place the greased O-ring in the cup on the tubing plate. Ensure that no grease is introduced into the hole.

An alternate method of applying Krytox® grease to O-rings is to place a *small* amount of grease in a small, clean plastic bag and spread it around (knead it). Then, place the O-rings in need of grease in the bag and knead it some more. This will effectively lubricate the rings, keep them free of contaminants, and provide a good storage container, all without getting excessive grease on your skin.

4. Repeat steps 5 and 6 for each O-ring in need of replacement.

5. Examine the tubing plate to verify that no contaminants are on the O-ring side. Magnification would be helpful. Replace the tubing plate by carefully placing it onto the calibration manifold. Make sure the O-ring side is down toward the pneumatic sliding manifold and the guide pins fit into the groves of the scanner's amplifier case.

6. Replace the Allen-head screws on the tubing plate. Also, tighten the screws on the carriers that were loosened. Tighten evenly, making sure the screws are only finger tight plus ¼ turn. It is important not to over-tighten the screws since the pneumatic seal is made using dynamic O-rings.

6.1.2 Transducer Carrier O-Ring Replacement

1. Place the scanner on its end with the electrical connector and amplifier case facing up and the tubing plate facing toward you. Please follow the guidelines of electrical care and cleanliness as described above.

2. Using the #0 Phillips-head screwdriver (PSI PN: 38-01-07-0), remove the two screws that hold the amplifier case to the scanner. Lift the amplifier case off the guide pins.

3. Orient the scanner so that the carrier on which the O-rings you wish to replace are facing up and toward you. For example, if you need to replace the O-ring for channel 1, place the scanner on its side with the electrical connector and amplifier case facing left and the tubing plate toward you.

4. Use an Allen wrench (PSI PN: 38-01-08-0564) to remove the two Allen-head screws on the carrier. Loosen the screws (one turn) on the other carrier that is located on the side on which you are working. Remove the carrier by lifting straight up, taking care not to bend the guide pins on the scanner.

5. Remove the O-rings from the carrier that are in need of replacement, using the needle nose tweezers. **NOTE: When removing the O-rings and cleaning the transducer carrier, be aware that the silicon pressure sensor is located less than 1/8 of an inch from the O-ring surface of the carrier.** Clean the O-ring cup with an applicator moistened with a cleaning fluid such as acetone, alcohol, or Freon (read all

manufacturer's warnings thoroughly), or any other substance that evaporates quickly and leaves very little residue. Remove any excess cleaner with the air supply as soon as possible. Do not blow air directly into the holes on the surface since that can drive fluid into the sensor and/or rupture it.

6. With clean hands, apply a small amount of Krytox® grease (PSI PN: 41-06-KRYX) to the palm of one hand and spread it evenly with your index finger. Place one new O-ring onto your greased palm. Work the O-ring around until it is evenly greased. The O-ring should shine when properly greased and there should be no white areas of excess grease on the O-ring. Make sure there is only a thin film of grease on the O-ring. Using your greased index finger, place the greased O-ring in the cup on the transducer carrier. Ensure that no grease is introduced into the hole that leads to the sensor.

Note

An alternate method of applying Krytox® grease to O-rings is to place a *small* amount of grease in a small, clean plastic bag and spread it around (knead it). Then, place the O-rings in need of grease in the bag and knead it some more. This will effectively lubricate the rings, keep them free of contaminants, and provide a good storage container, all without getting excessive grease on your skin.

7. Repeat steps 5 and 6 for each O-ring in need of replacement.

8. Examine the transducer carrier to verify there are no contaminants on the O-ring side. Magnification would be helpful. Look for defective O-rings (e.g., ones that are not round and shiny). Replace the carrier by slowly placing the new carrier on the guide pins. Ensure that the O-ring side is down toward the pneumatic calibration manifold and the connector plate is toward the scanner's electrical connector and amplifier case.

9. Replace the Allen-head screws on the carrier. Tighten evenly, making sure that the screws are only finger tight plus ¼ turn. Do the same for the other carrier that was loosened. It is important not to over tighten the screws since the pneumatic seal is made using dynamic O-rings.

10. Place the scanner with the electrical connector and amplifier case end facing up with the tubing plate facing toward you. Replace the amplifier case on the scanner by carefully placing it on the guide pins. Note, the bottom of the case utilizes one guide pin while the top is guided by two pins.

11. Replace the two Phillips-head screws that hold the amplifier case to the scanner by firmly and evenly holding the case down with one hand while evenly tightening the screws with the other hand. When fastening the amplifier case, take care not to let the case itself hit the connection pads on the transducer carrier. Fasten the screws finger tight plus ¼ turn.

12. Verify the correct operation of the scanner.

6.1.3 Piston O-Ring Replacement

1. Place the scanner on its end with the electrical connector and amplifier case facing up and the tubing plate facing toward you. Please follow the guidelines of electrical care and cleanliness as described above.

2. Using the #0 Phillips-head screwdriver (PSI PN: 38-01-07-0), loosen the two screws (two and one-half turns) that hold the connector and amplifier case on the scanner. Do not completely unscrew these screws.

3. Using the Allen-head screwdriver (PSI PN: 38-01-08-0564), loosen the two screws (one-half turn) on all carriers. Again, do not loosen these screws more than one-half turn. Use an Allen wrench (PSI PN: 38-01-08-050 for ESP-16HD or PSI PN: 38-01-08-0564 for ESP-32HD and ESP-64HD to remove the four Allen-head screws that secure the tubing plate onto the scanner. Carefully slide the tubing plate back and forth (about ¼ of an inch) several times. This is done to loosen the O-rings from the calibration manifold. Lift the tubing plate straight up.

4. Using your index finger, shift the calibration manifold back and forth several times to loosen its connection with the carrier O-rings. Carefully lift the scanner housing with one hand and turn it over, allowing the calibration manifold fall into the free hand. It is imperative that the calibration manifold does not fall onto a hard surface, since scratches on the manifold could result in pneumatic leaks. Using the air supply, apply about 30 psi (200 kPa) to the small holes that can be seen centered on the edge above the calibration manifold pistons. This should result in the pistons popping out of their cavity. If the pistons stick, apply a slightly higher pressure. Place your free hand over the scanner to prevent the pistons from popping out of the scanner housing.

5. Remove the piston O-rings from their slot and remove the old O-ring from each piston. With clean hands, apply a small amount of Krytox® grease (PSI PN: 41-06-KRYX) to the palm of one hand and spread it evenly with your index finger. Place one new O-ring onto your greased palm. Work the O-ring around until it is evenly greased. The O-ring should shine when properly greased. There should be no white areas of excess grease on the O-ring. Replace the greased O-ring on the piston and repeat for the other piston O-ring, if necessary.

Note

An alternate method of applying Krytox® grease to O-rings is to place a *small* amount of grease in a small, clean plastic bag and spread it around (knead it). Then, place the O-rings in need of grease in the bag and knead it some more. This will effectively lubricate the rings, keep them free of contaminants, and provide a good storage container, all without getting excessive grease on your skin.

6. Clean the piston cavity with a cleaning fluid such as acetone, alcohol, Freon (read all manufacturer's warnings thoroughly), or any other substance that evaporates quickly and leaves very little residue. Replace each piston into its cavity by placing the O-ring side of the piston in first and then pressing the piston completely into its cavity with one finger.

7. Refer to **Section 6.1.2 Transducer Carrier O-Ring Replacement** if replacement of all carrier O-rings is desired.

8. Clean and *lightly* grease the calibration manifold, being very careful not to get grease in the openings in the manifold. Replace the calibration manifold into the scanner. For ESP-16HD and ESP-32HD scanners, there are guide pins to prevent improper replacement. For the ESP-64HD, there are no guide pins. However, correct replacement may be assured by making sure that the side of the calibration manifold *without* holes is *down,* that the manifold position indicator is pointing up, and that the CAL hole on the manifold is closest to the scanner electrical connector. Further, verify that the two holes near the short edge end of the top surface are toward the amplifier case. The orientation of the calibration manifold is critical, and it is possible to assemble the scanner with the manifold oriented incorrectly.

9. Examine the tubing plate to verify that no contaminants are on the O-ring side. Magnification would be helpful. Replace the tubing plate by carefully placing it onto the calibration manifold. Make sure the O-ring side is down toward the pneumatic sliding manifold and the guide pins fit into the groves of the scanner's amplifier case.

10. Replace the Allen-head screws on the tubing plate. Also, tighten the screws on the carriers that were loosened. Tighten evenly, making sure the screws are only finger tight plus ¼ turn. It is important not to over-tighten the screws since the pneumatic seal is made using dynamic O-rings.

11. Place the scanner on its end with the electrical connector and amplifier case facing up and the tubing plate facing toward you. Fasten the two Phillips-head screws that hold the amplifier case to the scanner by firmly and evenly holding the case down with one hand while evenly tightening the screws with the other hand. When fastening the amplifier case, take care not to let the case itself hit the connection pads on the transducer carrier. Fasten the screws finger tight plus ¼ turn.

12. Exercise the calibration manifold a few times by applying 100 to 120 psi (700 to 850 kPa) alternating between C1 and C2.

13. Verify the correct operation of the scanner.

6.2 Tubulation Replacement Procedure

The following materials and tools are necessary for performing replacement of ESP scanner tubulations:

- ESP Maintenance Kit (PSI PN: ESP-MK)
- An ESD mat with wrist strap (observe correct grounding procedures)
- Small "needle nose" Pliers
- Cleaner such as Acetone or Ethyl Alcohol
- Cotton Swabs
- A single edged razor blade
- Soldering Iron (with clean tip)
- A can of compressed gas such as "Dust-Off"
- Paper wipes such as "Chem-wipes"

- A small clean flat plate such as a jar lid or microscope slide (this will be used to help apply the adhesive)
- A small lidded plastic container (used to hold the ESP scanner while repair is being performed on the tubing plate)
- Two small "Ziploc" bags for holding screws and o-rings.
- The "Kudl-Pak" case for the ESP scanner (used to hold the scanner amplifier case during the repair)
- A clean work surface

1. Place the scanner on an ESD mat and put on the wrist strap.

2. Using the #0 Phillips-head screwdriver (PSI PN: 38-01-07-0), remove the two screws holding the amplifier case to the scanner. Place screws in a "Ziploc" bag. Remove the amplifier case and place it in the "Kudl-Pak".

3. Place the scanner on a clean work surface and remove the anti-static wrist strap. The ESD mat and strap will be used again during the assembly process.

4. Remove the tubing plate.
    a. For 16HD and 32HD scanners, use an Allen wrench (PSI PN: 38-01-08-050 for ESP-16HD or PSI PN: 38-01-08-0564 for ESP-32HD) to remove the top plate retaining screws.
    b. For 64HD scanners, use the Allen wrench (PSI PN: 38-01-08-0564) to loosen the retaining screws for the upper two "carriers" abutting the tubing plate and remove the top plate retaining screws.

5. Place the screws in a "Ziploc" bag and the slide bar and carrier assembly in a plastic container.

6. Use a razor blade to trim the wooden stick of a cotton swab to a point to assist with the removal of the tubing plate o-rings.

7. Remove all o-rings from the tubing plate and place them in a "Ziploc" bag.

8. Clean all surfaces of the tubing plate. Use a cotton swab to clean the grease from all surfaces including the o-ring pockets.

9. Remove the damaged tubulation. If there is sufficient free area on the damaged tubulation, heat the tubulation with the soldering iron and grasp the tube and twist while pulling firmly.

10. If the tubulation breaks the remainder of the tube must be "drilled" out. Use the nose of the pliers to carefully flatten any raised portion of the tubulation.

11. Affix the appropriate drill bit (see the reference card included in the kit) in the pin vice (PSI PN: 38-01-09-01)

12. Drill the remainder of the broken tubulation and old adhesive from the tubulation pocket. Ensure that the pin vice and drill bit are angled correctly. Stop and examine the work frequently to ensure that the drill does not penetrate further than the original tubulation pocket.

13. Use the appropriate drill bit (see the reference card included in the kit) to ensure that the through-hole to the o-ring pocket is clear. Turn the tubing plate o-ring side up. Locate the o-ring pocket of the port of interest and blow compressed air through to remove debris. Insert the drill bit into the through-hole and gently remove any obstructions. Do not damage the o-ring sealing surface within the o-ring pocket. Do not drill through the tubing plate.

14. Clean the tubing plate, tubulation and o-ring pockets.

15. Clean the work surface.

16. Select a replacement tubulation from the ESP maintenance kit (see the reference card included in the kit). Test fit the tubulation to ensure correct height. The tube should be angled correctly.

17. Use the Loctite adhesive (PSI PN: 41-09-68005) to affix the new tubulation to the tubing plate. Trim the wooden stick of a cotton swap at an angel for use as an adhesive applicator. Place several drops of adhesive on a small plate. Examine the end of the tubulation which will be placed in the pocket. The adhesive will be placed as close as possible to the end of the tubulation without extending over the lip. Dip the trimmed applicator in the adhesive and place a thin bead around the circumference of the tubulation close the lip. Insert the tubulation in the pocket and twist slightly to distribute the adhesive.

18. Place the tubing plate in a clean location and allow curing for 24 hours.

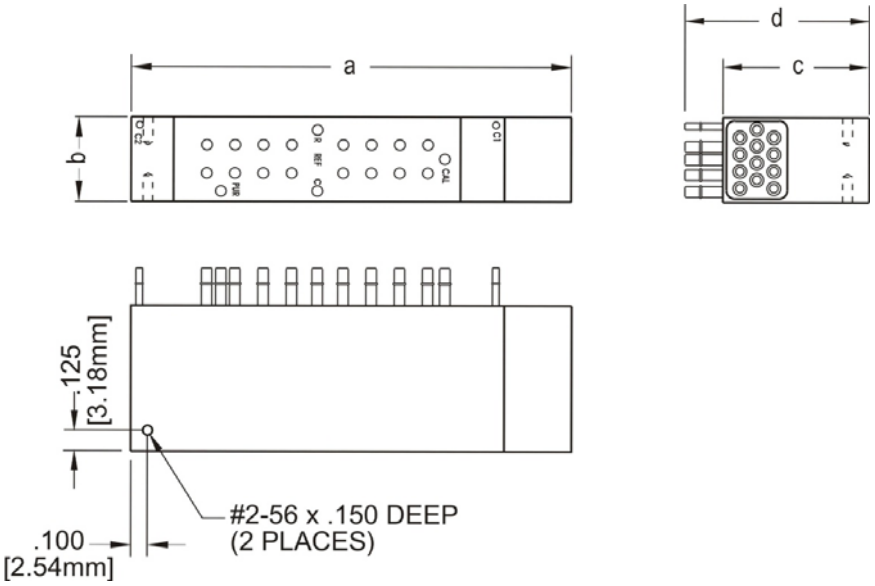
19. Once the adhesive has cured, inspect the tubing plate to make sure that the adhesive has not obstructed the through hole. Gently use the #74 drill bit to clean the through hole, if obstructed. Install the top plate o-rings. Affix the tubing plate to the scanner. Screws should be "finger" tight + ¼ turn.
    a. For 64HD scanners, tighten retaining screws for the two carriers abutting the tubing plate.

20. Place the scanner on the ESD mat. Put on the wrist strap. Attach the amplifier case to the scanner.

21. Perform a leak test, and accuracy test to verify correct operation of the scanner.

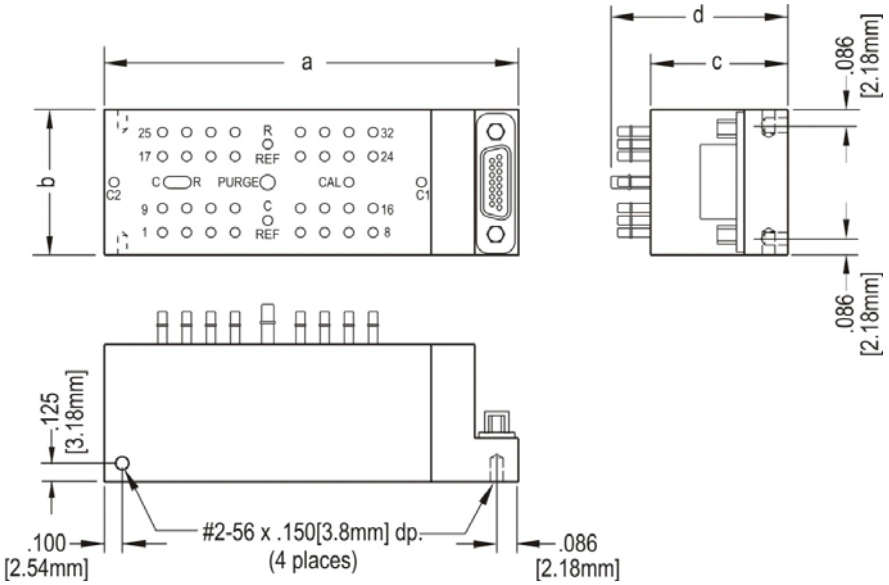
Appendix A

ESP-16HD Specification Drawing



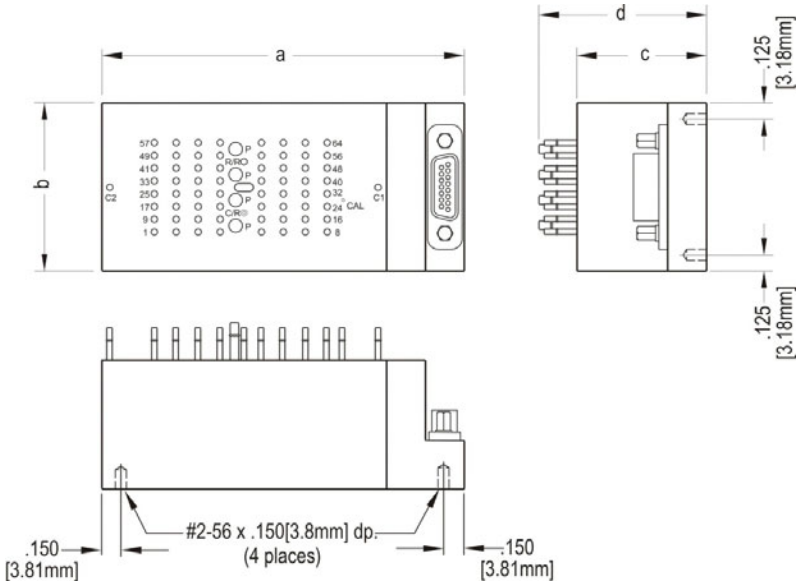
	ESP-16HD	a (length)		b (width)		c (height w/o tubes)		d (height incl. tubes)	
		in	mm	in	mm	in	mm	in	mm
Conventional	0.040" OD, straight	2.70	68.6	0.50	12.7	0.85	21.6	1.11	28.2
	0.040" OD, angled	2.70	68.6	0.50	12.7	0.85	21.6	1.07	27.1
	0.063" OD, straight	2.70	68.6	0.50	12.7	0.85	21.6	1.12	28.4
	0.040" OD, straight, purge	2.70	68.6	0.50	12.7	0.85	21.6	1.12	28.4
	0.063"OD, straight, purge	2.70	68.6	0.50	12.7	0.85	21.6	1.12	28.4

ESP-32HD Specification Drawing



	ESP-32HD	a (length)		b (width)		c (height w/o tubes)		d (height incl. tubes)	
		in	mm	in	mm	in	mm	in	mm
Conventional	0.040" OD, straight	2.80	71.1	1.00	25.4	0.93	23.7	1.17	29.8
	0.040" OD, angled	2.80	71.1	1.00	25.4	0.93	23.7	1.17	29.6
	0.063" OD, straight	2.80	71.1	1.00	25.4	0.93	23.7	1.18	30.0
	0.040" OD, straight, purge	2.80	71.1	1.00	25.4	0.93	23.7	1.36	34.5
	0.063"OD, straight, purge	2.80	71.1	1.00	25.4	0.93	23.7	1.36	34.5
	0.040" OD, straight, QDC	2.80	71.1	1.00	25.4	1.12	28.4	1.36	34.6
	0.040" OD, angled, QDC	2.80	71.1	1.00	25.4	1.12	28.4	1.35	34.3
	0.063" OD, straight, QDC	2.80	71.1	1.00	25.4	1.12	28.4	1.37	34.7
	0.040" OD, straight, QDC, purge	2.80	71.1	1.00	25.4	1.12	28.4	1.54	39.2
	0.040" OD, angled, QDC, purge	2.80	71.1	1.00	25.4	1.12	28.4	1.53	39.0
	0.063" OD, straight, QDC, purge	2.80	71.1	1.00	25.4	1.12	28.4	1.54	39.2
DTC Series	0.040" OD, straight	3.10	78.7	1.00	25.4	0.93	23.7	1.17	29.8
	0.040" OD, angled	3.10	78.7	1.00	25.4	0.93	23.7	1.17	29.6
	0.063" OD, straight	3.10	78.7	1.00	25.4	0.93	23.7	1.18	30.0
	0.040" OD, straight, purge	3.10	78.7	1.00	25.4	0.93	23.7	1.36	34.5
	0.063"OD, straight, purge	3.10	78.7	1.00	25.4	0.93	23.7	1.36	34.5
	0.040" OD, straight, QDC	3.10	78.7	1.00	25.4	1.12	28.4	1.36	34.6
	0.040" OD, angled, QDC	3.10	78.7	1.00	25.4	1.12	28.4	1.35	34.3
	0.063" OD, straight, QDC	3.10	78.7	1.00	25.4	1.12	28.4	1.37	34.7
	0.040" OD, straight, QDC, purge	3.10	78.7	1.00	25.4	1.12	28.4	1.54	39.2
	0.040" OD, angled, QDC, purge	3.10	78.7	1.00	25.4	1.12	28.4	1.53	39.0
	0.063" OD, straight, QDC, purge	3.10	78.7	1.00	25.4	1.12	28.4	1.54	39.2

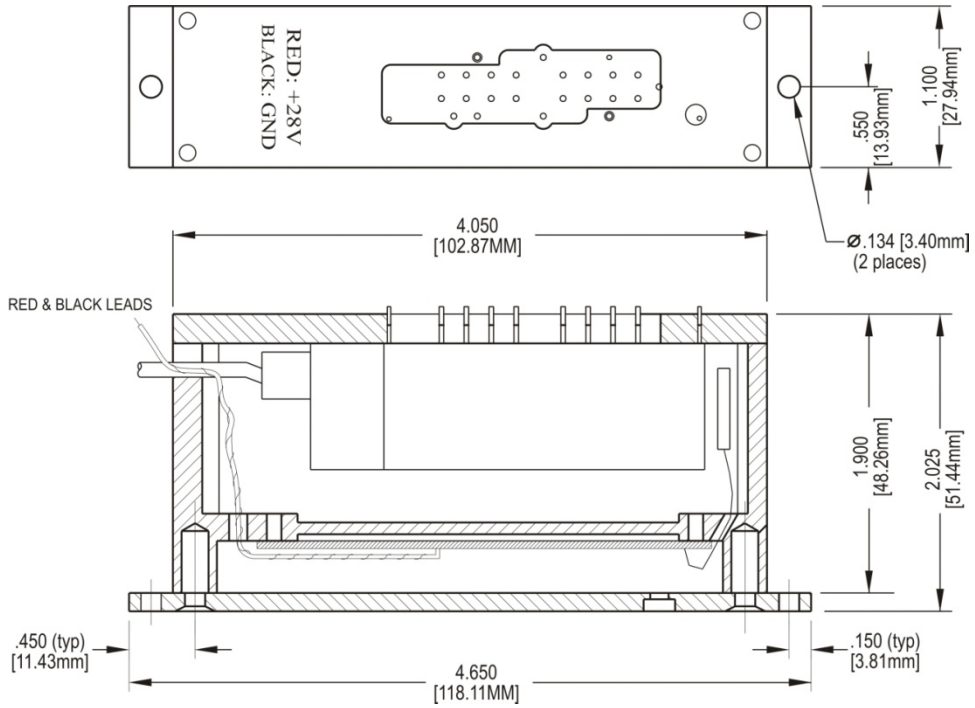
ESP-64HD Specification Drawing



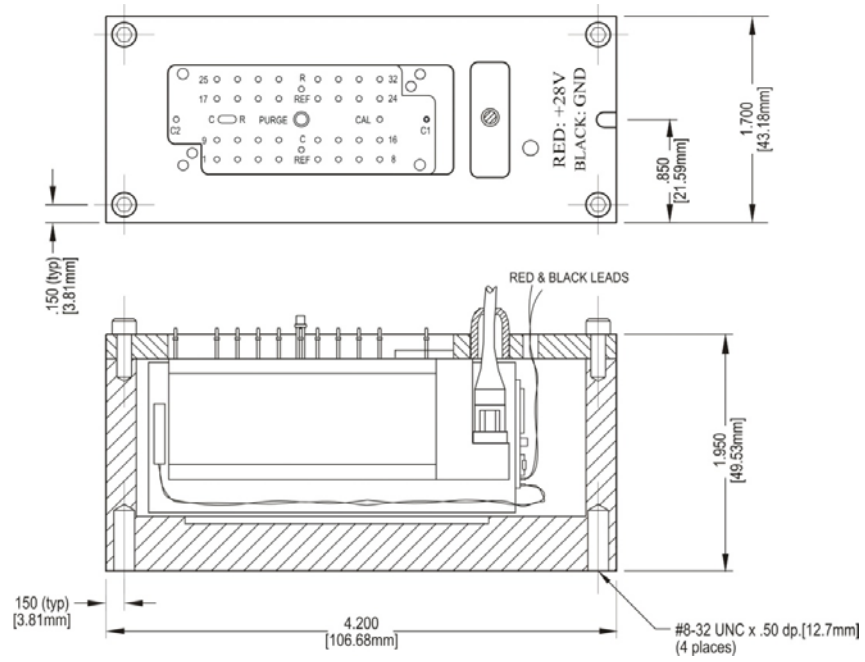
	ESP-64HD	a (length)		b (width)		c (height w/o tubes)		d (height incl. tubes)	
		in	mm	in	mm	in	mm	in	mm
Conventional	0.040" OD, straight	2.80	71.1	1.30	33.0	1.00	25.4	1.23	31.3
	0.040" OD, angled	2.80	71.1	1.30	33.0	1.00	25.4	1.19	30.1
	0.040" OD, straight, purge	2.80	71.1	1.30	33.0	1.13	28.6	1.55	39.4
	0.040" OD, straight, QDC	2.80	71.1	1.30	33.0	1.31	33.3	1.55	39.2
	0.040" OD, angled, QDC	2.80	71.1	1.30	33.0	1.31	33.3	1.50	38.1
	0.040" OD, straight, QDC, purge	2.80	71.1	1.30	33.0	1.31	33.3	1.74	44.1
	0.040" OD, angled, QDC, purge	2.80	71.1	1.30	33.0	1.31	33.3	1.55	39.5
DTC Series	0.040" OD, straight	3.15	80.0	1.30	33.0	1.00	25.4	1.23	31.3
	0.040" OD, angled	3.15	80.0	1.30	33.0	1.00	25.4	1.19	30.1
	0.040" OD, straight, purge	3.15	80.0	1.30	33.0	1.13	28.6	1.55	39.4
	0.040" OD, straight, QDC	3.15	80.0	1.30	33.0	1.31	33.3	1.55	39.2
	0.040" OD, angled, QDC	3.15	80.0	1.30	33.0	1.31	33.3	1.50	38.1
	0.040" OD, straight, QDC, purge	3.15	80.0	1.30	33.0	1.31	33.3	1.74	44.1
	0.040" OD, angled, QDC, purge	3.15	80.0	1.30	33.0	1.31	33.3	1.55	39.5

Appendix B

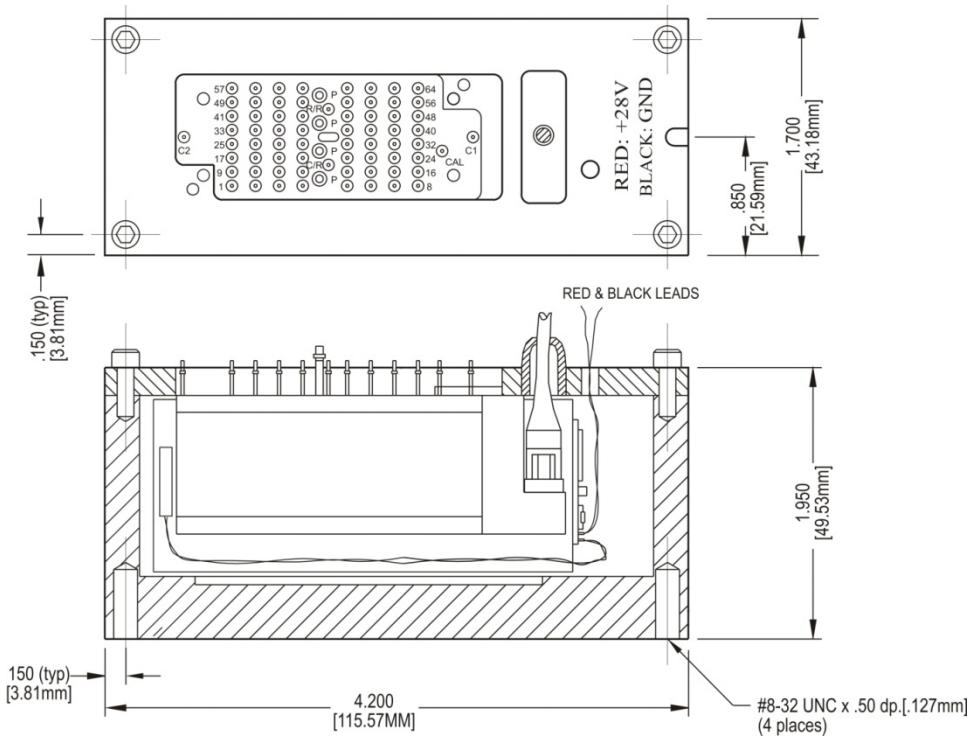
ESP-16HD Heater Chamber



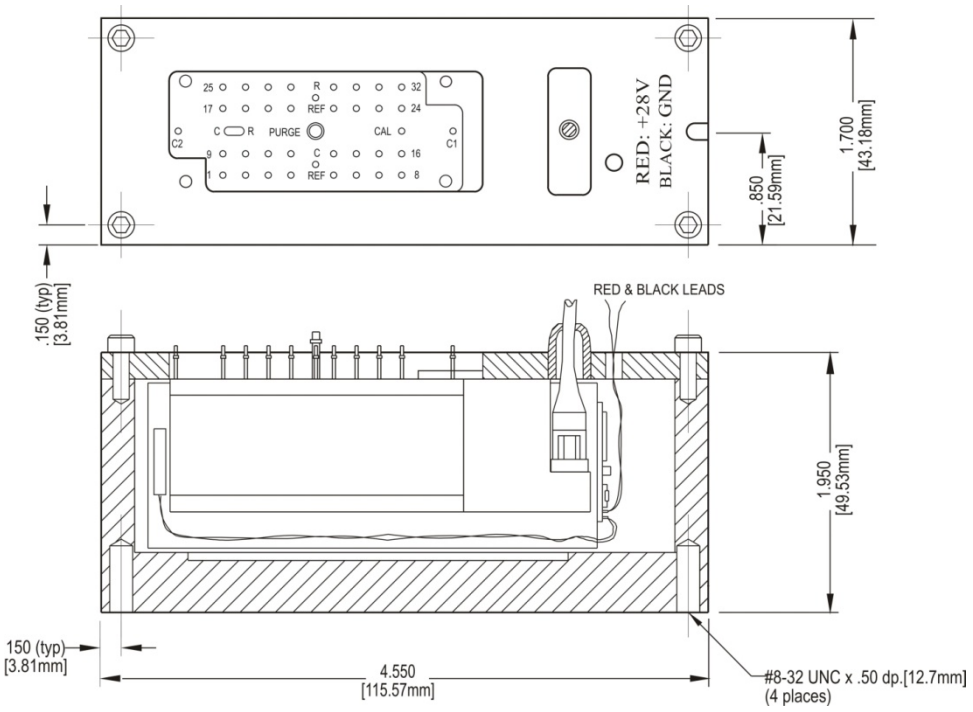
Conventional ESP-32HD Heater Chamber



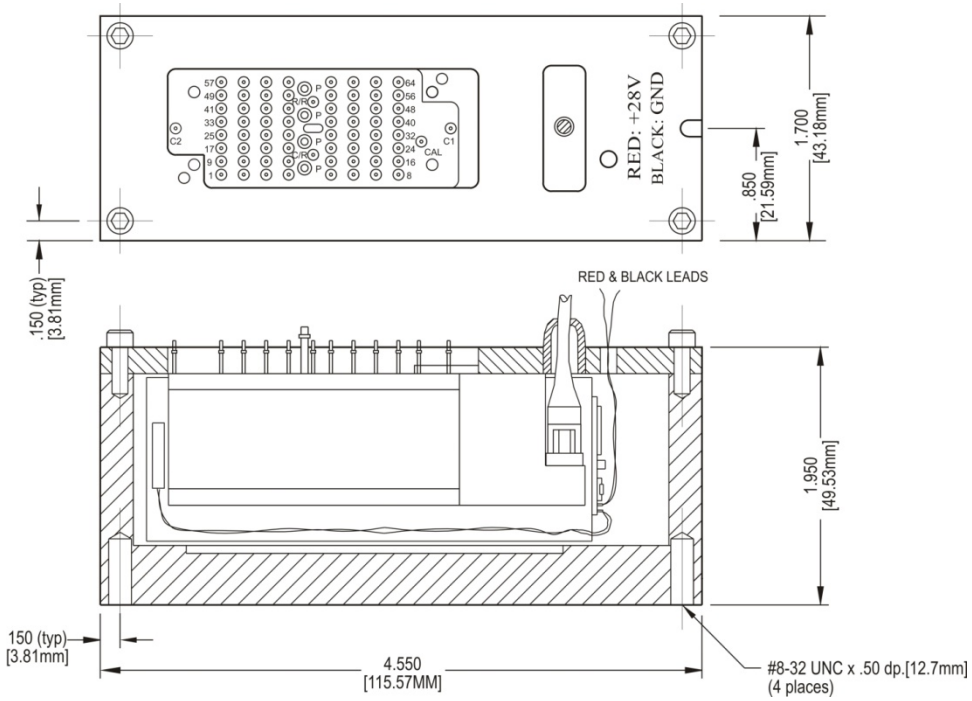
Conventional ESP-64HD Heater Chamber



DTC Series ESP-32HD Heater Chamber



DTC Series ESP-64HD Heater Chamber



Appendix C

Spare Parts

	PSI Part Number	Description
Maintenance Kit		
	ESP-MK	Universal maintenance kit for all ESP scanners **Note**: Items below are included in the maintenance kit along with spare screws and necessary hand tools.
O-Rings and Grease		
ESP-16HD	61-02-3023	Pressure Ports
	None Used	C1/C2 Control Ports
	61-03-40370	Pistons
	61-02-3143	Purge
ESP-32HD	61-02-3023	Pressure Ports
	61-02-3023	C1/C2 Control Ports
	61-03-40370	Pistons
	61-02-4762	Purge
ESP-64HD	61-02-3023	Pressure Ports
	61-02-3023	C1/C2 Control Ports
	61-03-46450	Pistons
	61-02-3143	Purge
	41-06-KRYX	Krytox GPL-206 grease
Tubulation and Adhesive		
	27-07-B300S	0.040" OD x .300" L SS Bulged Tubulation
	27-07-B350S	0.040" OD x .350" L SS Bulged Tubulation
	27-06-B350S	0.063" OD x .350" L SS Bulged Tubulation
	27-06-B550S	0.063" OD x .550" L SS Bulged Tubulation
	27-11-B500S	0.090" OD x .500" L SS Bulged Tubulation
	27-10-B550S	0.125" OD x .550" L SS Bulged Tubulation
	27-10-B750S	0.125" OD x .750" L SS Bulged Tubulation
	41-09-68005	Loctite 680 adhesive

Miscellaneous Parts

	PSI Part Number	Description
Tubing and Pliers		
	27-02-0040	Nylon tubing for .040" OD tubulations
	27-02-0062	Nylon tubing for .063" OD tubulations
	27-03-0125	Nylon tubing for .090" OD tubulations
	27-02-0187	Nylon tubing for .125" OD tubulations
	STP2-0000000000	Tubing pliers
Retaining Springs		
	12-90-2540	Retaining springs for .040" OD tubulations
	12-90-2562	Retaining springs for .063" OD tubulations
	12-90-2590	Retaining springs for .090" OD tubulations
	41-01-3511	Sealant for tubing to tubulations, 2 oz.

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